JPRS: 18,401

28 March 1963

OTS: 63-21439

SOVIET GEOPHYSICAL AND METEOROLOGICAL RESEARCH IN 1962

- USSR -

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Following is the translation of three articles in the Russian-language periodical Izvestiya Akademii nauk SSSR, Seriya geofizicheskaya (News of the Academy of Sciences USSR, Geophysical Series), No 1, Moscow, January 1963. Complete bibliographic information accompanies each article.

TABLE OF CONTENTS

MAGNETOTELLURIC SOUNDING IN GEORGIA

-USSR-

/Following is the translation of an article by G. A. Chernyavskiy and G. Ye. Gugunava in the Russian-language periodical Izvestiya Akademii Nauk SSSR -- Seriya Geofizicheskaya (News of the Academy of Sciences USSR -- Geophysical Series), No. 1, Moscow, January 1963, pages 147-151. The article, signed All-Union Scientific Research Institute of Geophysics, Academy of Sciences, Georgian SSR, Institute of Geophysics, was submitted to the editors 26 June 1962/

Abstract: On the basis of the results on magnetotelluric sounding work it is shown that the introduction of magnetotelluric exploration is very promising in Georgia when combined with other geological and geophysical methods.

Magnetotelluric methods of exploration have come into extensive use in geophysical practice in recent years. One of the most promising methods is magnetotelluric sounding. This method makes it possible to study the relief of the basement in regions with a thick (7-10 km) conducting layer of low resistivity. In such regions the mean-period variations of the magnetotelluric field occur at the low point of the sounding curve, thereby creating favorable conditions for the use of MTS (MTZ -- magnitotelluricheskoye zondirovaniye -- magnetotelluric sounding).

Up to 1960 magnetotelluric sounding was carried out by a number of investigators at individual points /1, 3/.

The first exploration work using the magnetotelluric sounding method was carried out by the VNIIGeofizika (Vsesoyuznyy nauchno-issledovatel'skiy institut Geofiz-

ika -- All-Union Scientific Research Institute of Geophysics) in 1960-1961 in Central Turkmenia along a continuous profile 400 km in length /See note/ and in the Vilyuyskaya tectonic depression (Yakutian ASSR) /See note/.

(/Note: G. N. Anishchenko, V. V. Golubkov, K. I. Nikitenko and G. A. Chernyavskiy, Otchet po teme 212, gl. XXI (Report on Subject 212, Chapter XXI), Publishing House of the VNIIGeofiziki, 1962/.)

(/Note: I. A. Yakovlev, Otchet o rabotakh opytno-metodicheskoy elektrorazvedochnoy partii (Report on the Work of the Experimental-Systematic Electric Exploration Party), Publishing House of the VNIIGeofizika, 1962/.)

In the fall of 1961 the VNIIGeofizika, in collaboration with the Institute of Geophysics of the Academy of Sciences of the Georgian SSR, carried out magnetotelluric sounding in eastern Georgia. This article describes that work.

1. Eastern Georgia is a complex geological region, whose deep structure has still been inadequately studied despite the fact that the entire area is covered by regional gravimetric and magnetic surveys.

Seismic research (GSZ -- glubokoye seismicheskoye zondirovaniye -- deep seismic sounding) was carried out along separate routes in zones where the crystalline basement is at a relatively shallow depth (up to 4 km) /4/.

A telluric survey was carried out during the years 1955-1960 under the direction of A. V. Bukhnikashvili and V. V. Kebuladze; long-period variations were recorded. The results of the survey were used to compile a map of the telluric parameter μ. A number of papers have been devoted to the geological interpretation of the results of these telluric investigations /5, 6/.

Magnetotelluric sounding was carried out at three points (Shindisi, Dusheti and Kakabeti) along a profile intersecting the area of the telluric survey from west to east (from the isolines of the telluric parameter μ = 5-6 to μ = 0.5).

The depth of the crystalline basement, consisting of pre-Paleozoic and Lower Paleozoic rocks, was shown by geological and geophysical data to vary from 3,770 m at Shindisi to 8,000 m at Kakabeti. The thickness of the sedimentary layer at Dusheti was assumed to be 6 to 7 km.

Logging data indicate that the geoelectric profile of eastern Georgia can be classified as the NA (four-

layer). The first two layers consist of Quaternary and Tertiary deposits with a relatively high conductivity which increases from west to east as the basement drops downward. The mean linear resistivity of this complex varies from 10-15 ohms/m to 2 ohms/meter. The third layer belongs to the Carboniferous suite of the Cretaceous and the clay-shales of the Jurassic with a resistivity of the order of 50 ohms/m. This layer, electrically merging with the high-resistivity rocks of the basement, is the electric reference horizon.

2. Magnetotelluric sounding was carried out using the prototype of a portable station constructed at the VNII-Geofizika. The station had the following components: oscillograph, two highly sensitive Brunelli H-magnetometers, a commutator panel and a power control unit.

The recording of E_x, E_y, H_x and H_y variations at each station lasted 40 to 50 hours. Variations with the period $T > 100$ seconds were registered at a paper speed of 20 to 25 mm/min.

The work was carried out in October and November at a time of relatively low telluric activity. Type Pc short-period pulsations of a quasi-sinusoidal shape were observed relatively rarely. The recordings most commonly carried trains of pulsations (P_t) of an irregular shape whose peak intensity was observed in the evening and night hours. Variations with periods of 70 to 150 seconds predominated in the frequency spectrum.

The mean amplitude of short-period pulsations at Dusheti and Kakabeti varied from 0.2 to 0.5 mv/km (telluric field) and from 0.3 to 1.5γ (magnetic field). The apparent period of variations varied from 15 to 500 seconds. The mean amplitude of telluric short-period pulsations at Shindisi was 1 to 7 mv/km.

The polarization of the field was different for periods of $T = 20$-60 sec and $T > 100$ sec. The travel-time curves for the telluric field, drawn for variations with $T > 100$ sec, were elongated in a sublatitudinal direction. The axes of the travel-time curves, drawn for mean-period variations, tend to have a meridional direction. The pulses of mutually-perpendicular components of the magnetotelluric field usually had similar configurations.

3. The processing of oscillograms involved the determination of the apparent periods and amplitudes of the quasi-sinusoidal pulses of the mutually-perpendicular components of the electromagnetic field. The magneto-

telluric sounding curves were drawn by the apparent impedance method and the mean impedance method [See note].

([Note]: T. N. Zavadskaya, Otchet po teme 212, gl. XIX (Report on Subject 212, Chapter XIX), Publishing House of the VNIIGeofizika, 1962.)

The values $\sqrt{T}$ are laid off at a logarithmic scale along the x-axis; the following values are laid off on the y-axis at the same scale:

$$\rho_{T_{xy}} = 0{,}2\,T\,|Z_{xy}|^2$$
$$\rho_{T_{yx}} = 0{,}2\,T\,|Z_{yx}|^2$$
$$\rho_T^* = 0{,}2\,T\,|Z^*|^2$$

where T is the period of variations in seconds. Z_{xy}, Z_{yx} are the apparent impedances in mv/kmγ, $Z^* = \sqrt{Z_{xy} \cdot Z_{yx}}$ is the mean impedance.

It was established that the value of the apparent impedances are dependent on field polarization. Z_{xy} and Z_{yx} were therefore determined by taking groups of pulses with approximately identical field polarization ($|E_x| \gg |E_y|$ for determination of Z_{xy} and $|E_x| \ll |E_y|$ for determination of Z_{yx}).

Fig. 1 shows the derived magnetotelluric sounding curves. Each point on the curves $\rho_{T_{xy}}$, $\rho_{T_{yx}}$ is the result of averaging 5 to 7 measurements. On the ρ^*_T curves each point is the result of a single measurement.

Curves with a clear minimum were obtained at Kakabeti (for the latitudinal component of the telluric field). These curves are characterized by a well-expressed right asymptotic branch with an angle of inclination to the x-axis of 63°, a narrow minimum, a steep left descending branch. A comparison of the curves with theoretical curves shows that in shape they are close to the three-layer type H with the parameters

$$\frac{\rho_2}{\rho_1} = \frac{1}{9} - \frac{1}{19}; \quad \frac{h_2}{h_1} = 1; \; \rho_3 = \infty.$$

At Shindisi the magnetotelluric sounding curves are represented only by a right branch.

When the curves are superposed $\rho_{T_{xy}}$ and $\rho_{T_{yx}}$ do not coincide with one another. The discrepancies of the values of the total longitudinal conductivity are: at Kakabeti -- 44%; at Dusheti -- 36%; and at Shindisi --

27%. This is evidence that the medium investigated is nonhomogeneous. The value of the total linear conductivity was determined by using the formula

$$S = 356\sqrt{T_S}$$

where $\sqrt{T_S}$ is the abscissa of the point of intersection of the asymptote of the curve with the line $\rho_T = 1$.

When determining the value of the mean linear resistivity the geoelectric profile was considered two-layered (it was considered that the conducting complex above the reference horizon is of great thickness). The value ρ_1 was computed by using the formula $\rho_1 = 1.32\ \rho_{T_{min}}$, where $\rho_{T_{min}}$ is the ordinate of the minimum on the magnetotelluric sounding curves. The thickness of the complex above the reference horizon (the thickness of the Quaternary and Tertiary deposits) was determined from the formula $H = \rho_1 \cdot S$.

4. Fig. 2 shows the results of sounding in comparison with the data for a telluric survey.

The values for the total linear conductivity change from west to east from 300 mho at Shindisi to 2,900 mho at Kakabeti and the values of the mean linear resistivity from 9 to 2.5 ohms/m. It can be seen from the graphs that the changes of the total linear conductivity and the telluric parameter μ are due not only to changes in the thickness of the complex above the reference horizon, but also to changes of mean linear resistivity ρ_1.

A comparison of the values of the telluric parameter μ with the values of the total conductivity make it possible to postulate that the nature of the reference horizon is similar for long-period variations (T = 15-60 min and for variations with periods of 100-500 sec, that is, both classes of variations fall in the interval S [7, 8].

On the basis of the resulting data an effort was made to make a quantitative interpretation of the results of the long-period telluric survey. By using the graphs of $\mu(S)$ and $\rho_1(S)$ part of the map of the telluric parameter μ was transformed into a map of total conductivity and then into a map of depths to the reference horizon. These maps characterize the general characteristics of change of the parameters of the conducting complex of Tertiary deposits for the area investigated.

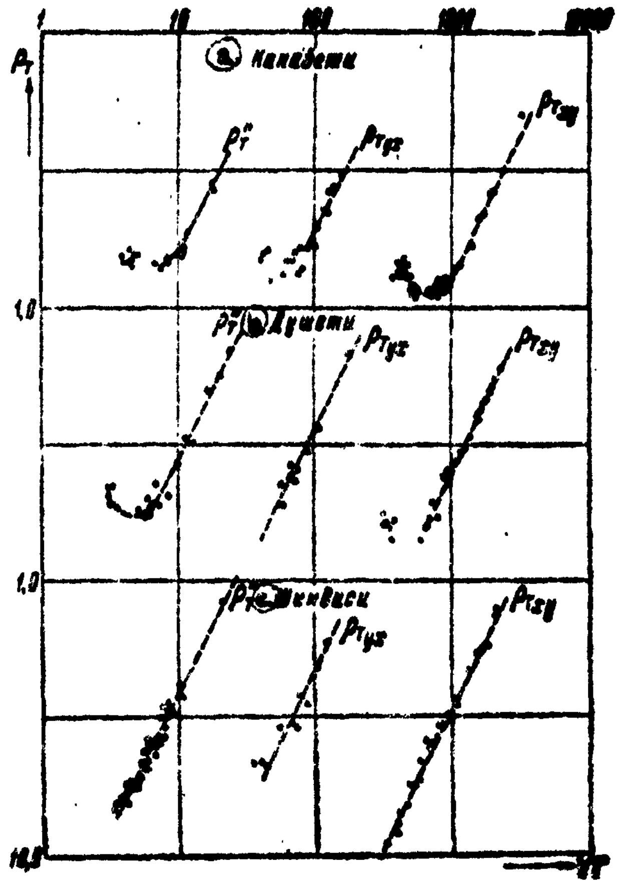

Fig. 1. Magnetotelluric sounding curves. Eastern Georgia, 1961. a -- Kakabeti, b -- Dusheti, c -- Shindisi.

Conclusions

1. The geoelectric conditions in the territory of Eastern Georgia are favorable for magnetotelluric sounding work.

2. The results of the magnetotelluric sounding work agree well with the results of a long-period telluric survey.

3. The study of the dependence of μ on S and μ on ρ_1 makes it possible to make a quantitative interpretation of the results of a telluric survey made in past years.

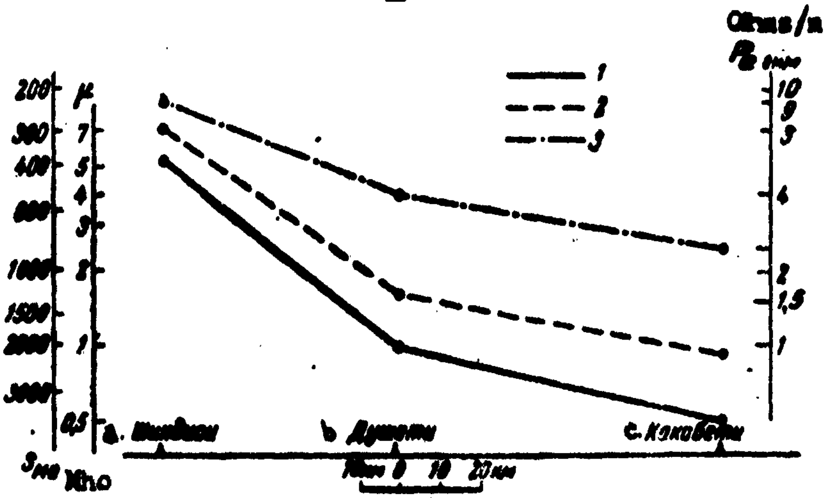

Fig. 2. Comparison of the results of magnetotelluric sounding and the data for a long-period telluric survey along the profile Shindisi-Dusheti-Kakabeti: 1 -- curve for the telluric parameter μ, 2 -- curve of s = total linear conductivity based on magnetotelluric sounding data, 3 -- curve of the mean linear resistivity based on magnetotelluric sounding data. a -- Shindisi, b -- Dusheti, c -- Kakabeti.

The conclusions drawn above indicate that the adoption of magnetotelluric exploration in the complex of geological and geophysical investigations is highly promising for the territory of Georgia.

The authors take this opportunity to express their deep gratitude to M. N. Berdichevskiy and V. V. Kebuladze for assistance given during the field work and the processing of data.

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CSO: 8447-D

RESEARCH ON CLOUD STRUCTURE AND THE SCIENTIFIC TASKS CONNECTED WITH THE INTERNATIONAL YEAR OF THE QUIET SUN

- USSR -

[Following is the translation of an article by A. Kh. Khrgian in the Russian-language periodical Izvestiya Akademii Nauk SSSR - Seriya geofizicheskaya (News of the Academy of Sciences USSR - Geophysical Series), No. 1, Moscow, January 1963, pages 169-176. The article was submitted to the editors 2 August 1962].

Modern knowledge of the macrophysics of clouds and their electric and other properties is surveyed. Future research on and organization of cloud observations in the USSR are outlined.

Cloud research has recently attracted the attention of geophysicists because forecasting clouds and precipitation is the most difficult task in synoptics and the aviation service, requiring profound knowledge of physics, and because the recent discovery of methods of artificially influencing clouds and precipitation has begun a completely new era in the use of active meteorological techniques. Together they make the subject of cloud physics important and interesting to a great many specialists, agricultural technicians, aviation personnel, etc.

Clouds are studied both by the airplane method (most widely and systematically developed in the USSR [1-3] and England) and by the laboratory method (more extensively used than in any other branch of science relating to the atmo-

sphere): observation of the processes of condensation, freezing, etc. in special condensation or "cloud" chambers. This many-sided experimental approach has created the foundation for a theory of cloud formation and precipitation. The latter has been successfully applied to the study of particle coagulation, distribution of the processes of freezing of the particles, etc. [4].

The years between 1955 and 1958 were marked in the USSR by extensive research on the microphysics of droplet clouds, spectra of drop sizes, particle composition, etc. A recent survey [1] shows that the substantial amount of material now gathered in the USSR and, to a lesser degree, in other countries provides a rough but satisfactory initial description of the microstructure of natural clouds. The simple laws deduced from the material are widely used for a variety of practical calculations [5, 6], e. g., for icing of airplanes, range of visibility, etc. This is presumably the reason that problems in cloud microphysics now rest on experimental material, which is sufficient at least for immediate theoretical formulations and practical needs.

The more complicated problems of cloud macrophysics have been much less studied. The formation and development of clouds is determined primarily by large-scale air currents,

their divergencies, vertical components, turbulence, etc. and, in part, by the processes of radiation and scattering of radiation. These macroscopic processes are closely connected with those considered by synoptic forecasters. They must complete their prognosis of a wind pressure field (synoptic or hydrodynamic) with a prognosis of the development of cloud systems and precipitation. Precipitation can be regulated and a sufficient amount of "artificial rain" can be obtained only if the process of regeneration, the process of natural restoration of a cloud, is thoroughly understood.

Thus, it is easy to see that the next ten years will be a period of widespread macrophysical cloud research, experimental and theoretical. Moreover, theory will often indicate the subsequent path of experimental research, the method of organizing it, etc.

To help solve the problems involved, 1964-1965 has been designated the All-Union Cloud Year (ACY) and it will form part of the program for the International Year of the Quiet Sun (IYQS) [7]. The organization of these observations does not come within the scope of this article, but it is obvious that the scientific plan will necessarily reflect in the best way possible the major problems in cloud research mentioned above. The following will help to improve weather forecasting and con-

tribute to our knowledge of methods of influencing clouds:

(1) study of cloud systems of fronts (including their cirrous parts) and the jet stream;

(2) investigation of the genesis and development of convective clouds;

(3) research on stratiform clouds (including those formed in an anticyclone);

(4) statistical characteristics of the altitudes and number of clouds of different shapes;

(5) study of cloud forms and systems in mountainous regions;

(6) investigation of the microstructure and chemical composition of condensation nuclei, particles of clouds and precipitation;

(7) observation of electric and optic properties of clouds;

(8) clouds over oceans and large bodies of water.

Since fronts are responsible in almost all climates for most of the precipitation, forecasting of frontal cloud systems is highly important. These systems are often "shortened" while preserving either the upper part, which yields very little precipitation (as often occurs in Central Asia), or the lower part (A. M. Borovikov [8]). "Models" of such fronts together with the conditions under which they are formed await refinement. Of interest from the standpoint of forecasting are the

cloud systems of the jet stream, where a great variety of Ci, Cc, As, Ac, and other clouds reflect the complex types of movement. These systems have been little studied, although the dynamic properties of the jet stream are quite familiar (cf. [9]). The possibility of organising observations of cloudiness of the "eastern waves" in the trade winds and of clouds in the intertropical convergence zone must also be considered [10].

The theoretical dynamic patterns of fronts have already been worked out in the Soviet Union for the "classical" frontal pattern [11, 12] and for a modified pattern where the principal factor in condensation is the turbulence of the layer between the surface of a front and the tropopause [13, 14]. This latter model also accounts, in principle, for the appearance of a separate upper cloud layer above the frontal surface. To check these patterns will require the organisation of observations or evaluations of the vertical movements and turbulence coefficient.

Similar to these observations is the investigation of cirri, in which careful observation together with synoptic investigation [15, 16, and, in particular, 17] reveals the effects of general ascensional motion, subinversion turbulence, convection, and even wave movements. In doing so it will be necessary to distinguish between the condensation

area proper in a cirrus and the area of particle precipitation (virga). These observations require a more complex technique: high-flying aircraft, improved microphysical apparatus, etc. However, the study of ice clouds is extremely important since their particles may serve as "seeds" in the formation of frontal precipitation. The possibility of influencing frontal clouds should also be studied, i.e., the possibility of artificial redistribution of their precipitation (for example, the plan to protect large cities from snowfalls and drifts).

Systems or areas of cirri are also of interest because these are the clouds that are chiefly observed from satellites. They are capable of influencing radiation of the earth, observations of terrestrial radiation and temperatures from satellites, etc.

Convective clouds, including thunderstorm and shower clouds, are a source of great danger both to aviation and to agriculture. Since highly promising methods of breaking up thunderstorm clouds have already been tested, there is great need of information on the structure of these clouds, their microstructure and water content, vertical movements at different stages of development, etc. Recent microsynoptic investigations [18] have shown that the areas of hail and heavy rain are complex in structure and they shift in complex fashion. Methods are now available for

6

simultaneous observations of the motion and thermal structure of convective clouds [3, 19]. These have led to the idea of medium-scale (5-20 km) atmospheric motion determining the convection field. However, a new pattern or "model" of a convective cloud to account for its known characteristics has not as yet been developed. The part played by "entrainment of air" from the sides, asymmetry of internal currents in a cloud, downward external motion, "friction" of an ascensional current against the surrounding air, etc. still awaits elucidation. Very little information is available on the structure of the upper part of clouds, the place where the "anvil" is formed.

For comparison with future observations from satellites, it is very important to study the relationship between Cu - Cb systems and wind field, shifting of winds, area of vergencies, etc. [20]. Cu and Cu over similar broad expanses of ocean are naturally of great interest for the theory of convection. Modern theoretical investigations [21] of convection and of the clouds related to it (dealing with both the actual process of cloud formation and the stationary, simpler models of motion developing above the condensation level) are highly valuable in clarifying the phenomena.

Such observations are also necessary for the organization of observations in the case of level or broken terrain in relation to the degree of instability of the troposphere, etc.

Photogrammetric investigations of the formation of convective clouds, their delicate structure, development, and disintegration could be extremely useful. It is occasionally somewhat easier to observe convective clouds in mountainous regions where they are sometimes "tied" to certain places and do not drift away from the observer. It is generally known that radar has made a major contribution to the study of convective clouds and efforts to modify them. The primary elements of convection discovered by radar (called "angels" abroad [22]) cannot be seen by any other method. They probably result in the formation of larger ascensional currents and clouds. Radiolocation methods of judging the intensity of turbulent motion [23] will undoubtedly be essential in studying cumuli and other cloud forms.

Of great significance in forecasting are the stratiform clouds, sometimes with the regular undulating form (Sc), sometimes without it (St), which are mostly formed under inversions. The theory of these clouds, which takes into account turbulent mixing in the subinversion layer and the advection of warm moist air, was worked out by L. T. Matveyev [13], V. S. Kozharin [14] and (earlier) by K. V. Klubovich, all of whom later made allowance for general slow vertical motion. Ye. M. Feygel'son [5] examined the influence of radiation of clouds and absorption of solar radiation therein, which determine not only

the details of thermal stratification in a cloud and the convective processes near its upper boundary, but also the process of upward growth of a cloud deck. The theory of condensation in such clouds was also considered by N. F. Bogdanova and M. V. Shvets [24]. In general, this type of clouds has been given more detailed theoretical study than all the others and we now have a fairly clear idea of the dynamic and thermal processes that take place in them. Several experimental investigations made by the author [25, 26] and one made by him jointly with K. G. Abramovich [27] showed that the existing theories describe fairly well the process of forming stratiform clouds. This formation is controlled by the processes of turbulence, which are conveniently characterized by the quantity Ri, and it varies with the slow vertical motion. The peculiarities of the boundary layer (Bernhardt [28]) leave some imprint on these clouds, which require more comprehensive study. In some cases the turbulence required to form St or Sc is presumably intensified in the boundary layer and is comparatively weak throughout the troposphere above it (F. . Vorontsov has described examples of such distribution of turbulence).

Study of the forms of the upper surface of cloud decks (successfully begun by A. F. Nepovitova [28]) has thrown light on the formation of clouds under the influence of radiation

cooling and upward destabilization of clouds and on the subsequent development of convection and intensification of condensation. In addition, the correlation noted by V. S. Kozharin between the distribution of the water content of a cloud and the velocity of ordered and turbulent motion [14] will facilitate the use of microphysical observations to determine accurately the processes that may predominate in a given case.

Synoptic investigations of clouds as well as calculations of their water content for the purpose of modifying them require a detailed climatological (statistical) analysis of the number, altitude, temperature, and other characteristics of different cloud forms. Specifically, to interpret the photographs of clouds taken from above, it is necessary to make separate estimates of the number of clouds at all three levels. This requires hourly estimates of the number of clouds of all forms, observation of their altitudes, high-speed photographing of the entire cloud, and observations from sounding airplanes behind the upper clouds. The territory of the Soviet Union is highly varied in this respect - from the White Sea area, where there is a record number of clouds throughout the year (the mean monthly number is 9), to the virtually cloudless Turkmenistan and Central Asia in general, where cloudiness in July comes to 0.2-0.4 but in the winter and spring displays the greatest variety of forms. Detailed

statistical processing of the altitudes, forms, and number of clouds separately for the various regions in 1964-1965 should yield a very comprehensive description of the clouds. It will probably be possible to find statistical methods (this idea has already been applied to climatology by S. A. Saposhnikova) of reducing such "ultrashort" series of observations to long ones in order to obtain statistically supported climatological data.

The great variety of topography in the Soviet Union provides exceptional opportunities for observing the cloud forms of mountainous regions - lee waves, lenticular clouds, banner clouds, etc. These observations are particularly valuable in that they throw light (especially if motion pictures are taken or base mapping of the clouds is used [30]) on the dynamic processes and delicate structure of the field of air motion over mountainous terrain. Of practical importance too are observations of frontal cloud systems over mountains, sharpening of fronts, development meanwhile of cloud systems both in thickness and in extent, rainfall intensification, etc. (cf. [31]). The advance of a cold front is much more pronounced in mountainous than in plains regions. Convective clouds over mountains also have many structural peculiarities [2]. They disintegrate rapidly if they originate at very high and "cold" levels; contrariwise, they become more intense under the influence of rugged terrain

and uneven heating of the slopes ([13, p. 131]). These features are important in efforts to modify clouds, for they indicate the part of the clouds in which to introduce the reagent and the method to be used.

We pointed out several times that the microstructure (drop size spectrum, shape and size of crystals, constituents of different crystals, water content, condensation nuclei) of clouds has been fairly well studied in recent years. Borovnikov [1, chapter 2] notes that aerologists, mostly in the Soviet Union, have made a major contribution to this field. The microstructure of cirri and the spectra of the larger ($r = 30 \div 200\mu$) drops - an important transitional stage to rain drops - has received less attention. However, microphysicists are confronted with a much more important problem, that relating to the theory of the processes of drop coagulation (Brownian, turbulent, etc. [33]) and to the theory of the propagation of a crystallization front in a cloud [4], i.e., the macroscopic theory of influencing clouds. Clearly, experimental verification of these theories in the near future will have to be based on microstructure observations. It will be remembered, however, that great progress was made in the Soviet Union during the International Geophysical Year in studying the chemistry of precipitation, clouds [34], and condensation nuclei, resulting in Soviet scientists gaining the leadership

in this field. This work must be continued, for it provides highly useful information on the origin (sea, industry) and properties of the nuclei.

There is no doubt that the process of precipitation formation should likewise be in the forefront of attention by investigators in the IYQS. Here the problems connected with the organization and plan of the work are more complicated because it is not a question of systematic network observations, airplane ascents, radar data, etc. but of individual research based on different ideas involving the use of theoretical, laboratory, and other methods. It is difficult to draw up a work plan for 1964-1965, the more so since it will have to take into account the findings of foreign scientists during the next one or two years.

Observations on the optic and electric properties of clouds constitute a special chapter. Although the most recent work [5] has not confirmed the old hypothesis of Mahl (?) that radiation by haze causes a marked drop in temperature, condensation, and then the formation of a cloud, the optic properties of haze - the condensation nuclei - should be studied in relation to the possible composition of the particles, relative humidity, etc. (This has been proposed to the ACY by Tashkent University in particular). The radiation properties of clouds, chiefly in different parts of the infrared spectrum, require detailed

experimental investigation, now that the theoretical foundations have been laid (cf. above). We expect a good deal of new information will be obtained by future weather satellites on the forms, temperatures, altitudes, and, perhaps, microstructure of clouds. The American Tiros I and II have shown that this is a highly promising approach. A weather satellite would not fulfill its assignment if it were restricted to simple photographing of clouds.

Little attention was paid during the past two decades to the electric properties of clouds and their effect on condensation and coagulation. The situation has now changed, and theories have been advanced on the charging of small drops [35, 36] and on the interaction and coagulation of individual charged and uncharged drops which show that this effect can be significant, although it is not yet clear how it "functions" in the aggregation of drops in a real cloud. A little information has been obtained on charges of different size drops in a cloud [37]. These observations ought to be expanded (there should be available a small number of airplanes for this purpose) and a laboratory check made to determine how the process of electric drop coagulation takes place. This might lead to the elaboration of a new method (main or auxiliary) for treating clouds, long the dream of such prominent geophysicists as V. N. Obolenskiy.

14

Another problem which might be approached the same way (although it is not one of the main tasks of the ACY) is the division of a cloud into areas of positively and negatively charged drops, i.e., the structure of a thunderstorm cloud and the origin of discharges therein). These observations should also be taken in cumulonimbi. Since the latter are dangerous for airplanes, the work started in the U.S.S.R. to devise an electroradiosonde (cf. [38]) should be vigorously pushed forward, although it is not likely to be widely used in the near future.

The IYQS will naturally entail the development of many new methods of observation, particularly radiolocation (which now enable us to observe the microstructure as well as the turbulence and ordered motion in clouds) and photographic methods, which are helpful in describing convection, wave processes, effect of mountains on currents and clouds, etc. The most difficult to develop will be methods of observing the structure of cirri from pressurized airplanes and moisture in the upper troposphere and stratosphere. About the latter we still know less, perhaps, than we do about the atmospheric ozone. Here even such indirect data on moisture as observations on the dissemination of bands of cirri (bands of gradually evaporating crystals) and disintegration of condensation traces behind airplanes may be useful.

The scope of this article does not permit us to discuss in greater detail the organization of observations in connection with the IYQS, in which networks of ground (including mountain, ship, and arctic) and aerological stations will have to take part. It is easy to predict that the airplane will be the major tool of the ACY, both the high-flying plane making upper-air or horizontal soundings and the ordinary plane with an experienced aerologist aboard. Investigations of characteristic situations (frontal cloud systems, extensive layers of wave clouds, convective clouds) will often require high-speed and "concentrated" simultaneous observations by an entire network in a certain region for several days at a signal from some synoptic center. Following the example of the IGY, such observations can be called "alerts".

All this work, as already noted, will serve at the same time as the Soviet contribution to the IYQS scheduled for 1964-1965. A great deal of aerological material will be collected simultaneously throughout the world along with observations on the composition of the atmosphere, ozone, etc., not to mention ionospheric and other data. This new mass of geophysical observations will be another important addition to our knowledge of the structure of the earth's atmosphere.

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5214
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STATISTICAL CHARACTERISTICS OF THE HORIZONTAL COMPONENT OF WIND VELOCITY AT ALTITUDES OF 6 TO 12 KM

-USSR-

/Following is a translation of an article by N. Z. Pinus of the Central Aerological Observatory in the Russian-language periodical Izvestiya Akademii Nauk SSSR, Seriya Geofizicheskaya (News of the Academy of Sciences of the USSR, Geophysical Series), No. 1, Moscow, January 1963, pages 177-182; the original article was submitted on 13 August 1962/

Abstract: This article gives the results of experimental investigations of spatial fluctuations of the horizontal component of wind velocity at altitudes of 6 to 12 km, the correlation coefficients and spectral functions and and their mathematical approximation. It is shown that the "minus 5/3 law" is correct for scales of horizontal motions to the order of several tens of kilometers.

Experimental investigations of the frequency characteristics of the horizontal component of wind velocity have been made until now primarily in the surface layer of air. Such investigations in the free atmosphere involve considerable systematic and instrumental difficulties, especially in the upper troposphere and lower stratosphere, because there they can be made only on aircraft flying at great velocity. Moreover, the use of acoustic (sonic) and inclinometer-type anemometers is at this time possible only on aircraft flying at a velocity of up to 250-300 km/hour.

The only method which makes it possible to measure the direction and velocity of the horizontal component of the wind with sufficient accuracy during

flights on high-speed aircraft is the use of Doppler systems in combination with a highly precise instrument recording the air speed of the aircraft. Doppler systems make it possible with a high degree of accuracy to determine the air speed and drift of the aircraft. By knowing these values it is possible to easily compute the wind velocity and direction. The possibilities of this method have been described in [1, 2].

By using the aircraft Doppler set in combination with the aircraft speed indicator the author obtained data on wind velocity and direction at altitudes of 6 to 12 km, measured with due accuracy, at points in space 3 to 4 km distant from one another.

The measuring apparatus was installed in a TU-104 and the measurements were made in horizontal flight in "areas" not less than 200 km in length. Experimental flights were made in the spring of 1960 in the Far East and in the winter of 1962 in various regions of the temperate latitudes of the European part of the Soviet Union. During this entire period a total of 115 experimental flights (200-km "areas") were successfully made. The majority of the experimental flights were at altitudes of 9 to 10 km.

The observational data were used to compute the statistical characteristics of the spatial fluctuations of the horizontal component of wind velocity. The degree of general disturbance of the field of wind velocities was estimated using the generally accepted value

$$\phi = \frac{\sqrt{\overline{u'^2}}}{\overline{u}}, \qquad (1)$$

where u' is the turbulent pulsation of the horizontal component of wind velocity and $\overline{u}$ is the mean wind velocity for the "area".

Computations have shown that at altitudes of 6 to 12 km and with wind velocities exceeding 50 to 60 km/hour the value ψ changes in rather broad limits: from 0.05 to 0.30. The vertical distribution of ψ first increases with altitude and has a peak in the atmospheric layers 7.5-8.5 and 9.5-10.5 km and then rather sharply decreases.

Of equal importance was the determination of the correlation and spectral characteristics of the spatial fluctuations of the horizontal component of wind velocity at altitudes of 6 to 12 km. The computation of the correlation coefficients when the pulsations of wind velo-

city are considered as a stationary random process

$$R(\Delta x) = \overline{u'(x)\, u'(x + \Delta x)} \qquad (2)$$

(2)

was done with a "Minsk-1" electronic computer. Experimental standardized correlation coefficients were grouped by altitudes and then averaged.

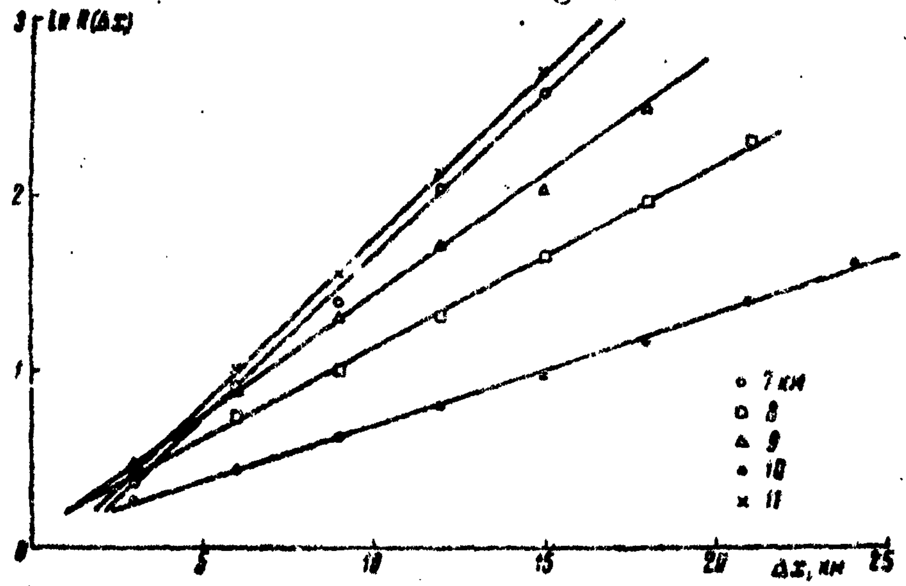

Fig. 1. Form of the correlation coefficient R(Δ x) in semilogarithmic coordinates

Table 1

Altitude, km	$\sqrt{\overline{u'^2}}$ km/hr	ψ	α, km^{-1}	R_0	L_0, km	n
7±0,5	11,0	0,127	0,1817	1,19	5,5	1,492
8±0,5	13,5	0,130	0,1054	0,93	8,5	1,574
9±0,5	10,8	0,165	0,1378	0,94	7,2	1,550
10±0,5	14,4	0,195	0,0[illegible]8	0,94	16,5	1,869
11±0,5	8,2	0,110	0,1936	1,16	5,1	1,337

In Fig. 1 the dependence ln R(Δx) and Δx is shown for different altitudes. It can been seen that there is an almost rigorous linear dependence between

these values. This makes it possible to approximate the experimental standardized correlation coefficients by the expression

$$R(\Delta x) = R_0 \exp - \alpha \Delta x \qquad (3)$$

Table 1 gives the mean values α and R_0 computed from the data in Fig. 1.

As might be expected, there is a definite dependence between the values α and ψ (Fig. 2): with an increase of disturbance of the field of wind velocities there is a decrease of the value α, that is, the correlation coefficient in this case decreases more slowly with an increase of Δx.

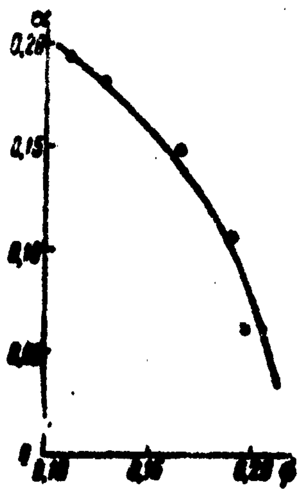

Fig. 2. Dependence of the value α on the degree of disturbance of the field of wind velocities (ψ).

A knowledge of the value α makes it possible to determine the correlation radius L_0 for the stationary random function $u'(x)$, that is, the distance Δx at which an appreciable correlation is maintained between the values $u'(x)$ and $u'(x + \Delta x)$. The values (x) and

$$L_0 = \frac{1}{\alpha} \qquad (4)$$

are given in Table 1. It can be seen that even on an average L_0 can attain 10 to 15 km.

The mean value $\overline{u'^2}$ is determined by the contribution of the fluctuations of the horizontal component of wind

velocity of different frequencies. In dependence on the nature of the field of fluctuations the determined frequencies will make the maximum contributions and thus to a considerable degree determine u'^2, whereas the influence of fluctuations of other frequencies will be insignificant. This can be seen from the spectral density of energy distribution $S(\Omega)$, being a Fourier transform for the correlation coefficient $R(\Delta x)$.

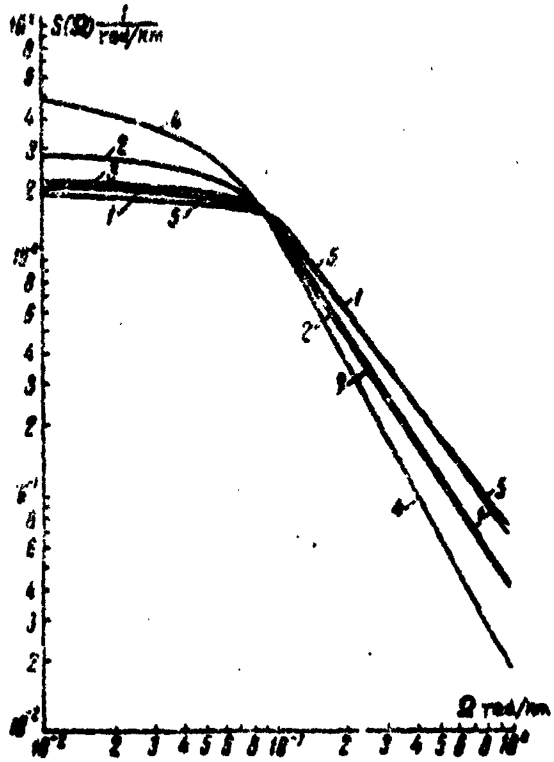

Fig. 3. Curves of the standardized spectral density for altitudes of 6 to 12 km. 1 -- 7, 2 -- 8, 3 -- 9, 4 -- 10, 5 -- 11 km.

It follows from (3) that the standardized spectral density of energy distribution is

$$S(\Omega)=\frac{1}{\pi}\int_0^\infty R(\Delta x)\cos\Omega\,\Delta x\,d(\Delta x) \qquad (5)$$

and can be represented in the form

$$S(\Omega) = \frac{1}{\pi}\int_0^\infty R_0 e^{-\alpha\Delta x}\cos\Omega\,\Delta x\,d(\Delta x) \qquad (6)$$

where Ω is spatial angular frequency, in our computations measured in rad/km.

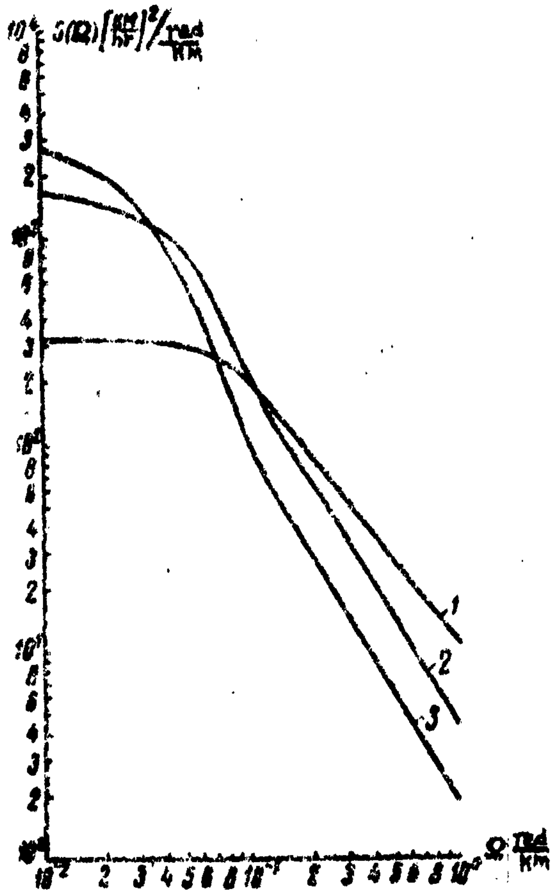

Fig. 4. Curves of spectral density: 1 -- in Cs clouds with δ^1, 2 -- in Cs clouds with δ^2, 3 -- outside clouds with δ^2.

It follows from (6) that the standardized spectral density of energy distribution for the horizontal component of wind velocity is defined by the expression:

$$S(\Omega) = \frac{R_0}{\pi}\frac{\alpha}{\alpha^2+\Omega^2} \qquad (7)$$

Fig. 3 shows curves of the standardized spectral density for different altitudes, computed by using (7). The experimental curves $S(\Omega)$ do not cover the part of the spectrum for the high frequencies. This is the result of a peculiarity of the described method for measurement of wind velocity and direction aboard an aircraft equipped with a Doppler system.

The nature of the curves $S(\Omega)$ is naturally determined by the value α. With a decrease of α (increase of ψ) in the spectrum of the random function the small frequencies assume great weight and the curve of spectral density is extended upward; but with an increase of α (decrease of ψ), on the other hand, the curve is flattened.

Graph 3 shows that changes of $\overline{u'^2}$ are determined primarily by changes in the contribution of fluctuations of the horizontal component of wind velocity with frequencies Ω less than 10^{-1} rad/km.

An analysis of Fig. 3 shows that there is the following approximate dependence between the spectral density of energy distribution $S(\Omega)$ and frequency Ω:

$$S(\Omega) \approx \Omega^{-5/3} \tag{8}$$

corresponding to the Kolmogorov-Obukhov "2/3 law" [3,4]. Table 1 gives the mean values of the power n for different altitudes. Since the scale of turbulent motions is

$$L = \frac{2\pi}{\Omega} \tag{9}$$

it therefore follows that the "minus 5/3 law", as follows from Fig. 3, is correct for the horizontal component of wind velocity with scales of motion to the order of several tens of kilometers.

During the experimental flights there was in some cases a bumping of the TU-104 aircraft, most commonly during flights within or directly at the upper boundary of Cs clouds. The bumping of the aircraft is for the most part caused by vertical gusts of air of atmospheric disturbances of relatively high frequencies [5, 6].

It is undoubtedly of interest to clarify the peculiarities of the distribution of spectral density of fluctuations of the horizontal component of wind velocity in zones of the atmosphere in which aircraft bumping occurred. At the same time it should be remembered that in a cloudless atmosphere the horizontal extent of

zones with aircraft bumping is 5 to 6 times shorter than the length of the "area" which we selected for the experimental flights. The latter is comparable only with the zone of bumping in Cs clouds.

The intensity of atmospheric turbulence causing the bumping of aircraft was estimated from the scale given in Table 2.

Table 2

Characteristics of aircraft bumping	Intensity of turbulency in units	Range of increases of aircraft overloads in fractions of g (9.81 m/sec²)
Calm flight	6^{0}	< 0.05
Slight bumping	6^{1}	0.05-0.20
Moderate bumping	6^{2}	0.21-0.50
Strong bumping	6^{3}	0.51-1.00
Very strong (storm) bumping	6^{4}	> 1.00

Table 3

Characteristics of flight conditions	Intensity of aircraft bumping	$\sqrt{\overline{u'^2}}$ km/hr	ψ	α, km^{-1}	R_0	I_0
In Cs clouds	6^{1}	13.8	0.135	0.1891	0.95	5.2
In Cs clouds	6^{2}	17.0	0.140	0.0500	1.02	20.0
Outside clouds	6^{2}	16.0	0.267	0.0245	0.95	40.9

This table shows that the correlation coefficient, when there is moderate bumping of the TU-104 aircraft, is characterized by a smaller value of the power α than in the case of weak bumping of the aircraft. The values u'^2 are in this case relatively large.

Fig. 4 shows the curves of spectral density for correlation coefficients described by the data in Table 3. As can be seen, for moderate aircraft bumping the curves $S(\Omega)$ are greatly elongated upward in the region of small frequencies.

The data cited still do not give the necessary information on the relations between the fluctuations of the horizontal and vertical components of wind velocity at altitudes of 6 to 12 km. We will investigate this

problem in the future.

In conclusion the author expresses deep gratitude to M. M. Kirpichev, V. I. Chernysh and L. V. Shcherbakova for computations made on the "Minsk-1" electronic computer.

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